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Image processing-based automatic gradation of stone aggregates

Tự động hóa việc xác định cấp phối hạt của cốt liệu đá sử dụng kỹ thuật xử lý ảnh

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Abstract

Gradation strongly influences the mechanical properties of stone materials. This paper aims to employ image processing methods to develop a simple tool for automatic gradation of stone aggregates. The methods of image thresholding, Gaussian filtering, median filtering, morphological closing, and contour analysis are employed. The output of the newly constructed system is the plots demonstrating particle size distribution. These plots can be used for further inspection of aggregate gradation. The system has been developed in Python and with the help of the OpenCV library.

Keywords: Stone aggregates; particle gradation; image processing; automation in construction; OpenCV.

Tóm tắt

Cấp phối hạt có ảnh hưởng lớn đến tính chất cơ học của các vật liệu đá. Bài báo này sử dụng các phương pháp xử lý ảnh kỹ thuật số để phát triển một công cụ đơn giản nhằm tự động hóa việc xác định cấp phối của cốt liệu đá. Các phương pháp đã được sử dụng bao gồm kỹ thuật phân ngưỡng ảnh, bộ lọc Gaussian, bộ lọc trung vị, kỹ thuật lấp điểm ảnh, và phân tích đường viền. Đầu ra của hệ thống là các biểu đồ thể hiện phân phối kích cỡ hạt. Các biểu đồ này có thể được sử dụng cho các phân tích sâu hơn về cấp phối hạt của vật liệu đá. Hệ thống đã được chúng tôi phát triển với ngôn ngữ Python và thư viện OpenCV.

Từ khóa: Vật liệu đá; cấp phối hạt; xử lý ảnh; tự động hóa trong xây dựng; thư viện OpenCV.

1. Introduction

Gradation is an important factor that affects the mechanical properties construction materials such as cement concrete, asphalt concrete, etc. The conventional aggregate size classification mainly relies on manual batch sieving [1]. The purpose of this process is to identify the distribution of the diameters of all particles within a batch. This can be achieved using a set of sieves with pre-determined mesh size (refer to Fig. 1.1). The manual batch sieving is time-consuming and inefficiency [2]. Thus, rapid automatic classification is helpful for construction practitioners to shorten the

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time required for particle size gradation. In addition, as demonstrated in [3], the diameter measured by the conventional sieving method is associated with random errors. Particles going through a sieve can have one dimension that is larger than the mesh size of the sieve. This fact can lead to inaccurate particle size gradation.

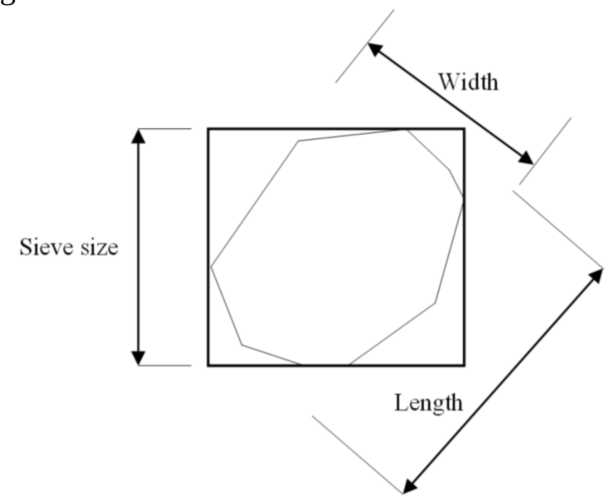

Figure 1.1. Sieve size, length, and width of a particle

Particularly for construction processes that require frequent and rapid gradation analysis, the laborious and error-prone manual sieve analysis is not suitable. Following the current trend of automation in construction [4, 5], this study attempts to develop a simple tool for increasing the productivity and accuracy of the particle size gradation process. The methods of image thresholding, Gaussian filtering, median filtering, morphological closing, and contour analysis are used. Thus, the new system is able to perform fast and real-time particle size gradation without the need of complicated and costly sieving equipment. However, the current system is the result of an initial study on computer vision-based particle size gradation performed by the authors. Thus, several limitations of the current method are discussed and potential extensions of the paper are pointed out in the next sections.

2. The proposed image processing method used for particle size gradation

The image processing-based method used to compute the distribution of the particle sizes is carried out in the following steps:

(i) Material preparation: In this step, a batch of stone aggregates is collected from the construction size and put on a flat surface with a white background. A digital camera mounted on a tripod is used to capture the image of the batch. A Canon EOS M10 was used in this study. The collected image has the size of 1419x861 pixels.

(ii) Image calibration: This step is to determine the actual size of a pixel [3]. Herein, one pixel corresponds to 0.2 mm.

(iii) Image filtering methods of Gaussian and median filters with a window size of 7x7 pixels are used to smooth the image and removes unwanted noise.

(iv) Image thresholding with a user-defined threshold value is used to binarize the image. Herein, the threshold value is experimentally found to be 180. Additionally, the morphological closing operator is used for image enhancement.

(v) Image contour analysis [6] implemented with the OpenCV library [7] is used to detect each particle within the scene. This method has been demonstrated to be effective for object segmentation [8].

(vi) A bounding rectangle is draw for each particle using the function provided in the OpenCV library. Subsequently, the width and the height of this rectangle are found. The diameter of a particle is determined as the maximum value of the width and the height.

(vii) A set of sieves with known mesh size is selected and used for particle gradation.

(viii) Operations on vector and matrices provided by the numpy Python library. These operations are used to compute the distribution of particle diameters. Consequently, the distribution can be visualized via bar charts and line dot plots.

3. Experimental results

In this section of the paper, the newly constructed system is validated using a case study. Herein, a batch containing 36 stone particles was prepared. The image of the batch captured by the Canon EOS M10 is shown in Fig. 3.1. Subsequently, the Gaussian and median filters are employed for image enhancement. Image thresholding is then performed on the smoothed image to delineate stone particles from the white background (refer to Fig. 3.2).

Figure 3.1. The original image of the batch

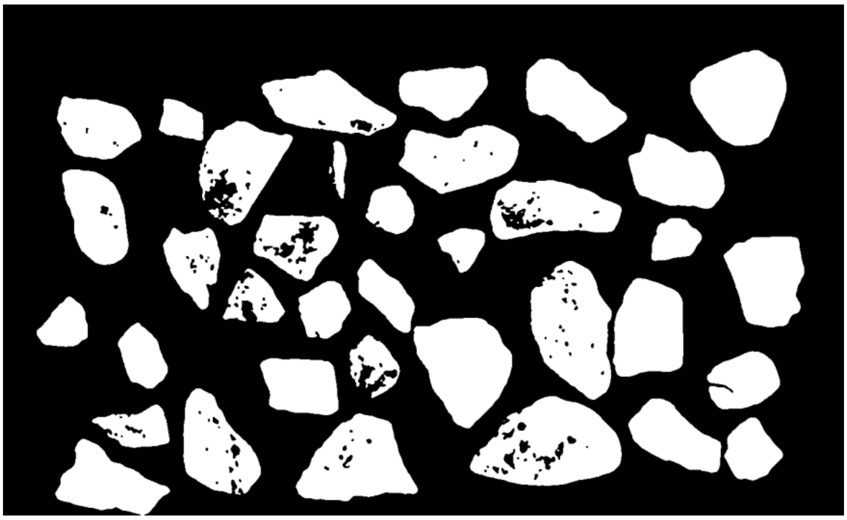

Figure 3.2. The result of the image thresholding process

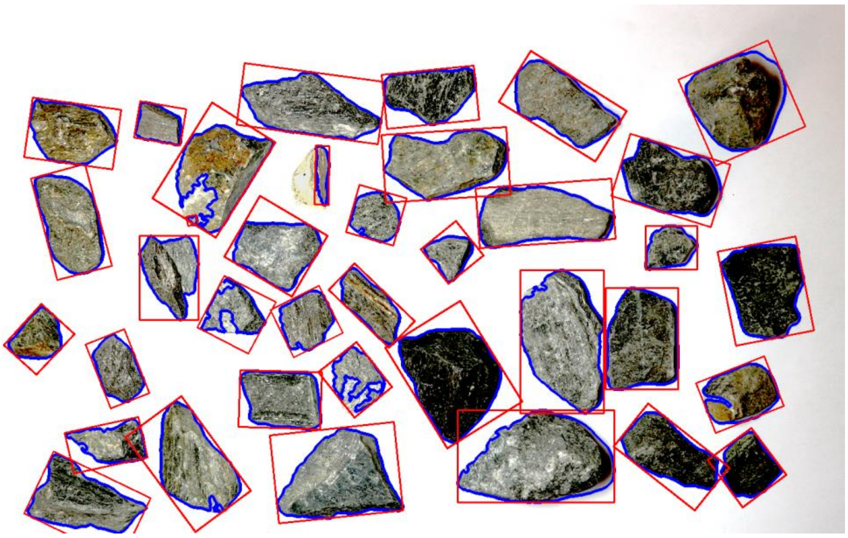

Figure 3.3. Identification of individual stone particles with bounding rectangles

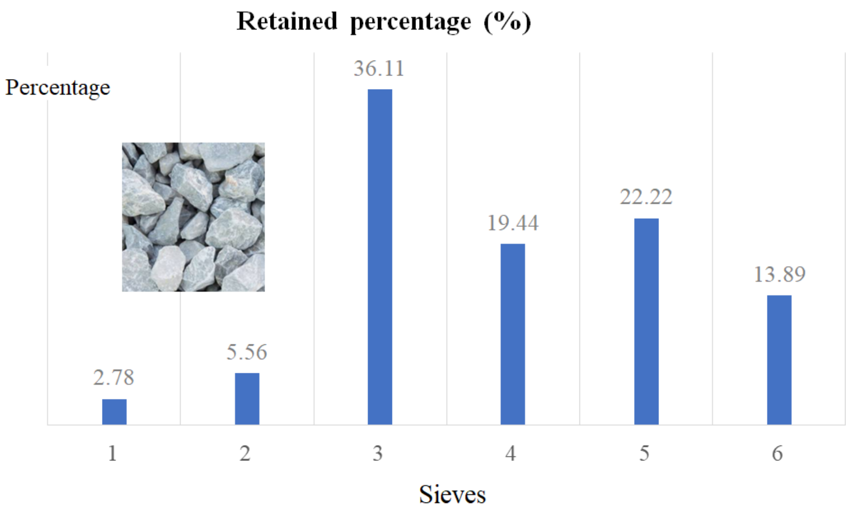

Figure 3.4. Retained percentage of each sieve

Based on the binarized image, the contour analysis algorithm [6] is used to detect individual particles. The contours are shown as blue polygons in the Fig. 3.3. Accordingly, a bounding rectangle is draw for each particle. The diameter of a particle is calculated as the maximum value of the width and height of its bounding rectangle. This study selected a set of six ASTM test sieves with the mesh sizes of 50, 45, 31, 25, 19, 13.2 mm. The measured particle diameters are compared to the values of the mesh sizes to determine the particle size distribution of the selected batch. Finally, the particle size gradation results are presented in Fig. 3.4 and 3.5. Herein the sieves with the mesh sizes of 50, 45, 31, 25, 19, 13.2 mm are denoted as sieve number 1, 2, 3, 4, 5, and 6, respectively. As shown in these graphs, the new system is able to graphically display the gradation of the selected batch. These graphs can be further used for in-depth analysis on the particle gradation of stone aggregates. The experiment is implemented on a computer platform with the Intel(R) Core(TM) i7-11800H and 16GB of RAM. The processing time of the experiment is 1.45s. This means that the system requires only 0.04s for processing one particle.

Nevertheless, the system in its early stage of development also suffers from several limitations. The first limitation is the measurement error caused by a particle's shadow. As can be seen from Fig. 3.3, an area of a particle can be enlarged due to the effect of its shadow. Perhaps, a more meticulous adjustment of the light source or camera position can help to fix this problem. In addition, several areas in particles having bright texture can be misclassified as the background. It is because the current model employs a simple image thresholding for delineating the particles from the background. More sophisticated approaches such as image texture analysis, image enhancement, and deep learning-based segmentation can be helpful to correct such misclassifications. In addition, the current method computes the particle distribution in terms of particle number. Gradation analysis in terms of particle mass is currently not possible. These limitations of the current approaches are going to be considered in our future works.

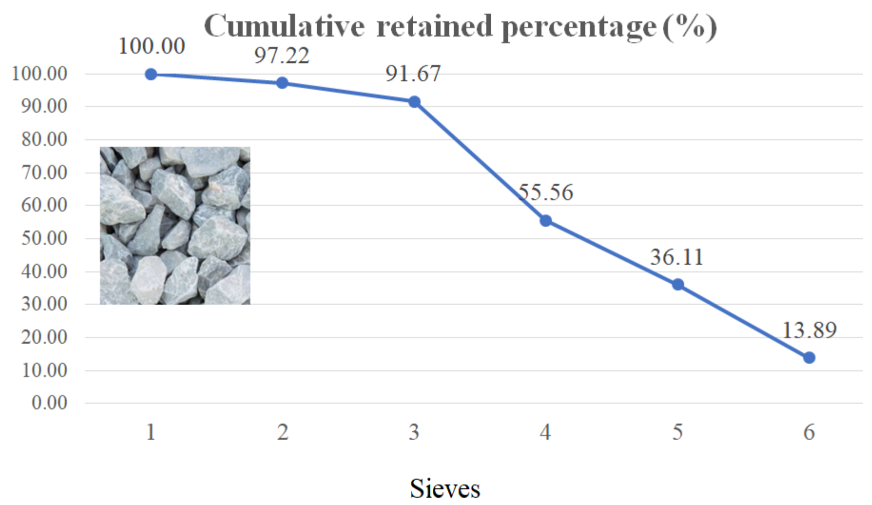

Figure 3.5. Cumulative retained percentage of each sieve

4. Conclusion

This paper has developed an image processing-based method for computing the particle gradation of an aggregate batch. Image thresholding, Gaussian filtering, median filtering, morphological closing, and contour analysis are used by the current method. The new system was developed in Python with the help of the OpenCV library to facilitate its construction and implementation. Experimental results show that the computing phase of the system is fast with only 0.04s per stone particle. In addition, the system yields the retained percentage of each sieve and the cumulative retained percentage of each sieve that can be helpful for further inspection of aggregate gradation. Future works should dedicate to the investigation of advanced computer vision methods to improve the system performance with respect to the particle's shadow, the bright texture, and the identification of the particle's mass.

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